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NATIONAL WORKSHOP ON SHOCK AND BLAST WAVE RESEARCH IN INDIA: THE PAST, PRESENT, AND FUTURE (NWSBRI-2017)

October 12-13, 2017



UNDERSTANDING, ACCELERATED

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*Energy Research and Technology Group
CSIR - Central Mechanical Engineering Research
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1. ENCHANTING WAVES

*Dr. Gopalan Jagadeesh
Department of Aerospace Engineering
Indian Institute of Science
Bangalore-560012*

Abstract

The phenomenon of “Shock Waves” referred here, as “Enchanting Waves” is commonly associated with aerospace engineering/astronautics and in particular with supersonic flight. Shock waves appear in nature whenever the different elements in a fluid approach one another with a velocity larger than the local speed of sound. Dissipation of energy, retardation of the velocity, flow turning and information transfer in high-speed flows are some of the fundamental reasons behind the occurrence of shock waves in supersonic/hypersonic flows.

A number of methodologies/facilities to generate shock waves of requisite strength have been designed and indigenously built in the Laboratory for Hypersonic and Shockwave Research (LHSR) in Indian Institute of Science (IISc), Bangalore. Novel techniques such as retractable aero-spikes, smart coatings, forward facing jets and concentrated energy deposition have been developed for reducing the aerodynamic drag around vehicles flying at hypersonic speeds. Innovative devices to recreate large scale blasts within the confines of the laboratory have also been developed. Concurrently, utilizing the remarkable ability of shock waves to instantaneously enhance the pressure and temperature in the propagating medium, shock wave assisted non-intrusive needleless drug delivery system, gene gun, cell transformation device, sandal oil, polyphenol and caffeine extraction techniques from natural products, and wood preservative impregnation techniques have also been developed in IISc. A broad overview of the recent research and technology development activities in LHSR will be presented in this talk.

2. Beyond Merely Seeing: Quantitative Non-Intrusive Diagnostics for Understanding Flows

*Dr. L. Venkatakrisnan,
Head, Experimental aerodynamics,
CSIR- NAL
Bangalore- 560 017*

1. Introduction

THe visualization and measurement of flows for understanding their physics and subsequent control have been the subject of innumerable investigations. This effort is aided by several kinds of measurement techniques. Broadly speaking, these techniques can be divided into intrusive and non-intrusive kinds. As is indicated by the term, non-intrusive methods have the significant benefit of being able to document a flow without interference from the measurement technique. As such, these methods should in principle be preferred over those that are intrusive.

The non-intrusive flow diagnostics techniques can broadly be grouped into three types: surface flow visualization, scattering from flow tracers, and density sensitive flow visualization. These can be of either the qualitative or quantitative type. Most quantitative techniques provide qualitative data in addition to quantitative data. A large number of these are laser and image based. These again can be point measurements or full-field measurements. Very often the resolution of the data available is limited by the capacity of the imager or the ability to illuminate the flow field. A great many techniques exist; these include, but are not limited to: surface visualization using oil flow, wall tufts, chemical sublimation, off-body visualization by smoke flow, dye flow, hydrogen bubbles, speckle photography, density changes, laser induced fluorescence, measurement by oil film skin friction measurement, particle image velocimetry, laser Doppler velocimetry, pressure sensitive paints and interferometry.

2. Flow Visualization

Flow visualization is one of the most effective tools in flow analysis. It has helped immensely in elucidating basic fluid mechanics principles and in understanding complex fluid flow. Flow visualization makes visible a property of a flow field to facilitate better observation and therefore analysis of a phenomenon. Normally most fluids either gaseous or liquid are transparent and therefore invisible to the eye unless a special technique to render them visible is applied. Several flow visualization techniques have been developed for routine application in wind/water tunnels.

2.1. Surface Flow Visualization

Surface flow visualization plays important part in understanding of flow physics by visualization of the flow pattern very close to the body surface. Typically, in this method, the surface is coated with the thin layer of a material, which upon the interaction with the

fluid flow develops a certain visible pattern. This pattern can be interpreted qualitatively and, in some cases, it is even possible to deduce quantitative data of the state of the flow close to the surface.

2.1.1 Oil Flow Visualization

Images from surface oil flow visualization demonstrate the depth of understanding that can be obtained from a simple visualization experiment. However, when the body under consideration is not two-dimensional; the interpretation of images is difficult. Venkatakrishnan and Karthikeyan¹ proposed a method of photogrammetric resection based on a comprehensive camera model to map oil flow visualization images on to the surface grid of the model. The result of this is shown in Figure 1. The data which is exported in the VRML format allows for user interaction in a manner not possible with two-dimensional images. The format has the added advantage of being able to obtain the precise location of flow features resulting in extraction of quantitative data from a predominantly qualitative technique

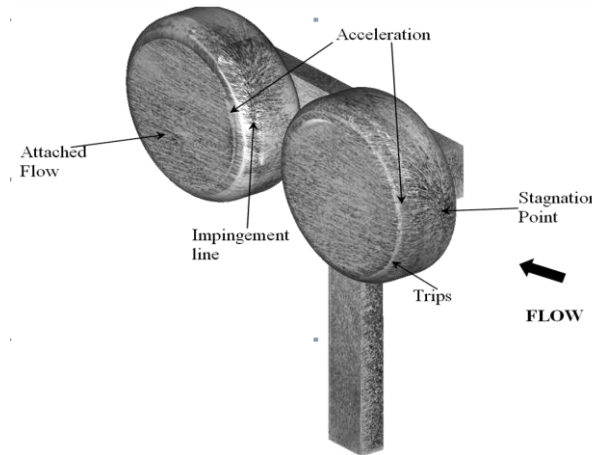


Fig 1. Landing gear model (one half) with texture mapped oil flow visualization data. (From [1])

2.1.2 Pressure Sensitive Paint Technique

The Pressure Sensitive Paint technique (PSP) is a method that provides quantitative surface pressure on the test article under investigation. The PSP method is based on the property of photo-luminescence of certain organic compounds. The article is sprayed with PSP and excited by UV light and luminescence emitted is captured using a CCD camera.

The capability of the system to generate data on complex aircraft configurations is demonstrated here on a 1:20 scale model of a fighter aircraft at freestream Mach numbers of 0.5 in the 1.2m wind tunnel at CSIR-NAL. Figure 2 shows a PSP

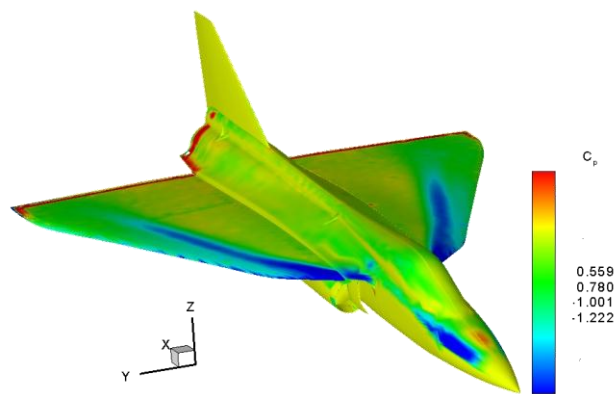


Fig 2. PSP map on the leeward side of a fighter aircraft showing flow features and quantitative data.

the distribution of pressure in terms of a coefficient of pressure. The map shows clearly the regions of low pressure (indicated by the blue regions) in the primary vortices over the delta wings as well as around the forebody and a zone of higher pressure at the nose below the cockpit facing the flow. The data show the incredible resolution enabled by the technique, limited only by the resolution of the sensor, as opposed to discrete measurements allowed by conventional methods such as pressure taps.

2.2. Off-body Flow Visualization

Background Oriented Schlieren

The Schlieren technique while exceedingly useful is limited by its qualitative nature. Attempts to make quantitative estimates of density using calibration have been found to be exceedingly cumbersome. Venkatakrishnan and Meier² validated the Background Oriented Schlieren (BOS) technique combined with filtered back-projection tomography, which provides the mean density field in a 2D plane. The extraction of a desired plane using Filtered Back Projection Tomography was carried out by Venkatakrishnan³.

Figure 3 shows the density field around an elliptic cone¹⁸ at $M=2$. The image which has been shown in a cutaway fashion to illustrate the capability of the technique to document the density field, exhibits the flow features of the shock wave from the tip and the density field around the body. The BOS technique has been applied to a large variety of flows, from the micro-explosions and wind tunnel applications described above to nozzles, microjets, full-scale helicopters in flight and full-scales. These applications have spawned a number of variants of BOS including Coloured Grid BOS (CGBOS), Retroreflective BOS (RBOS), Natural Background BOS, and Pulsed illumination BOS.

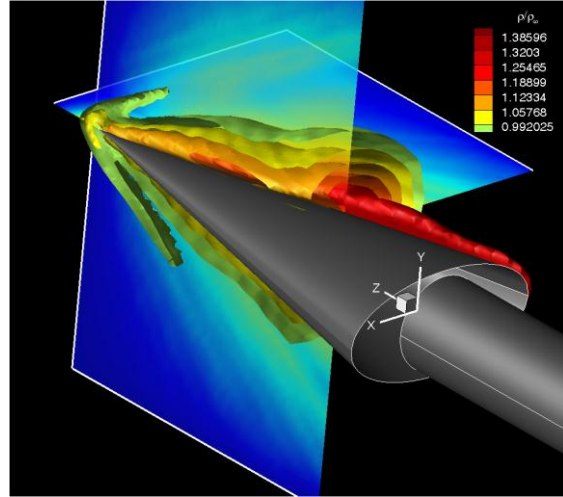


Fig 3. BOS generated density field of $M_x=2$ flow over elliptic cone at incidence (From [4])

3. Flow Velocity Measurement Techniques

The measurement of the velocity field of a flow using intrusive probes, always carries with it the possibility of interference with the flow and thereby influence over the quantity it seeks to measure. Laser based techniques have provided a way to make non-intrusive measurements of the three-component velocity by usage of a seed in the flow to scatter the laser light. Care must be taken though to ensure that the chosen seeding fulfils the needs of neutral buoyancy and Stokes drag to follow the flow with fidelity.

3.1. Particle Image Velocimetry

The Particle Image Velocimetry (PIV) technique is one answer to the challenge of obtaining data simultaneously at different spatial locations which is imperative for

resolving non-stationary flow structures. The measurement of the velocity field using PIV is based on the ability to accurately record and measure the positions of small tracers suspended in the flow as a function of time. The velocity is then deduced as the displacement divided by the time interval. This can be carried out as 2D PIV or 3C Stereo PIV.

Stereo PIV was employed to study asymmetry in the absence of propeller flow, over a Micro Aerial Vehicle. Figure 4 shows the vorticity at field at the first and last cross planes. The iso-surfaces of the vortex cores are also plotted as also the stream traces through the vortex cores. The port side has higher magnitude of positive vertical velocity component in the tip; lower magnitude of negative vertical velocity component in the inboard region and lower magnitude of tangential velocity component near the surface compared to the starboard side. These correspond to the flow pattern from oil flow visualization.

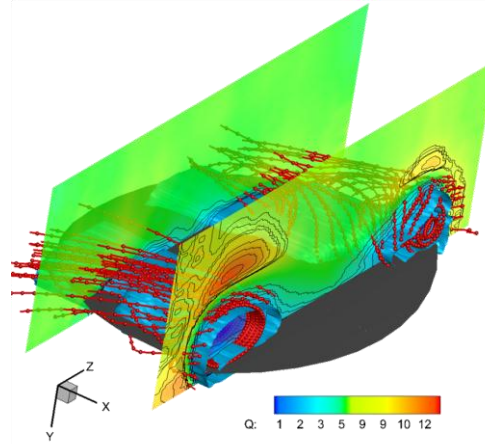


Fig 4. Three component velocity field over MAV at 24° incidence for Propeller Off (From

4. Future Outlook

Non-intrusive measurement techniques have made a significant impact on measurement technology in aerodynamics. The capabilities of these techniques have received a fillip due to improvements in illumination, imaging sensor and computing capabilities. The recent improvements in time resolved volumetric PIV, fast PSP, and BOS indicate that the goal of accurately measuring velocity, strain, density and pressure in 2D or 3D regions of a flow field, be it steady or unsteady, laminar or turbulent, compressible or incompressible is quite achievable. Further, the data, which are achieving resolutions hitherto not possible with conventional measurements, allow better understanding of flow physics.

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3. *Uses of Shock wave for aerothermodynamics characterization ISRO's vehicles*

K. Srinivasan, P.K. Maurya, S. Subash, J A Tennyson, B. Murugan & S. Pandian
Vikram Sarabhai Space Centre,
Thiruvananthapuram-695022*

Shock tubes/tunnel are research tools used primarily for aerothermodynamics characterization of re-entry vehicles, air breathing propulsion systems etc. by constructively utilizing the potential of the shock waves. In ISRO, the use of shock wave for aerothermodynamics characterization started on the need to characterize the heat flux on the ascending SLV-3 / PSLV heat shields and for the TPS design/optimization. The first re-entry mission of ISRO, viz., SRE demonstrated the usefulness of shock tunnel as tool for generating design data on heat flux distribution over the body. With ISRO future programs like SCRAMJETS, RLV's, HSP etc., the role of shock tunnels need not be over emphasized.

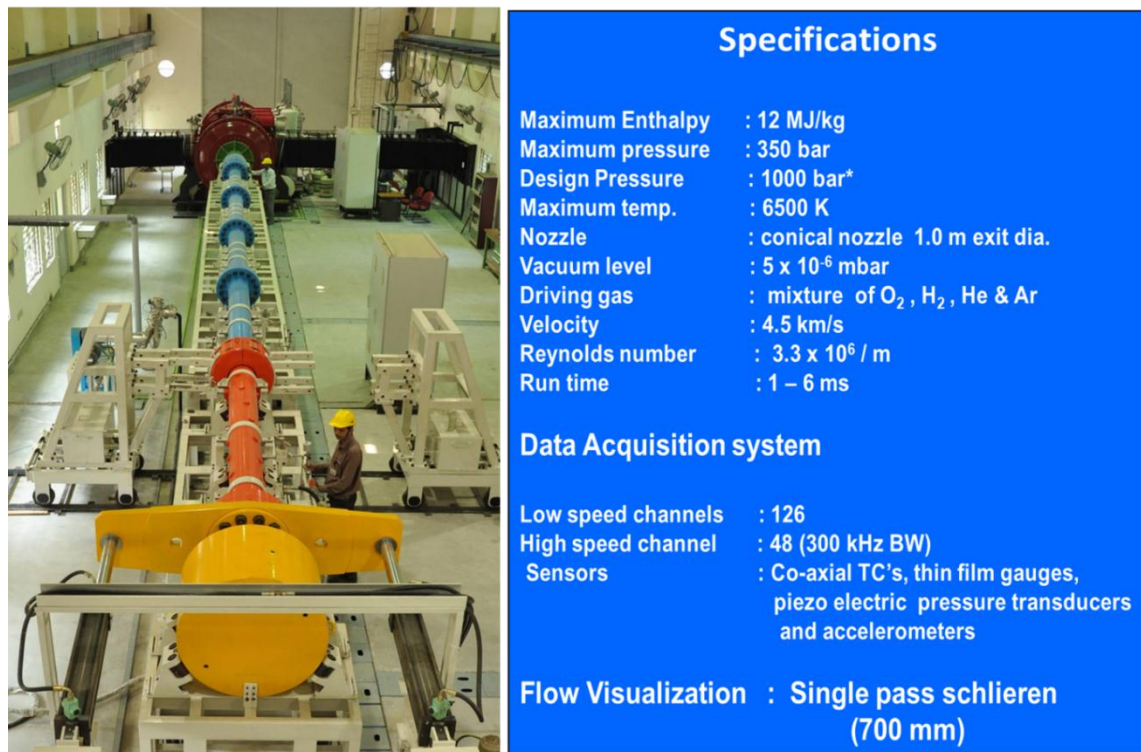


Fig. 1. Photograph and specification of 1m combustion driven shock tunnel

In order to meet ISRO's future requirements, a 1m combustion driven shock tunnel has been indigenously designed and commissioned at VSSC. Photograph of facility is given in Fig 1. Combustion driver as potential driver was chosen to meet enthalpy simulations up to 12 MJ/kg. The combustion driver uses a mixture of H₂, O₂ He and Ar gases to generate different burst pressures. A maximum post combustion pressure of 350 bar has been achieved in combustion driver. A typical pressure trace in combustion driver is given in Fig 2. Detailed studies were carried out to finalize the number of spark plugs,

location, mixing time etc. and based on the results spark plugs in two helix configuration is used in combustion driver.

Combustion driver has the potential to vary the post combustion speed of sound which is used to obtain more runtime in the test section by tailoring. Inert gases like Argon, Nitrogen are added in the H_2 , O_2 He mixture to get different shock speeds. A typical plot of P_5 with 5 ms runtime at an enthalpy of 2.5 MJ/kg is shown in Fig. 3 showing the effectiveness of tailoring.

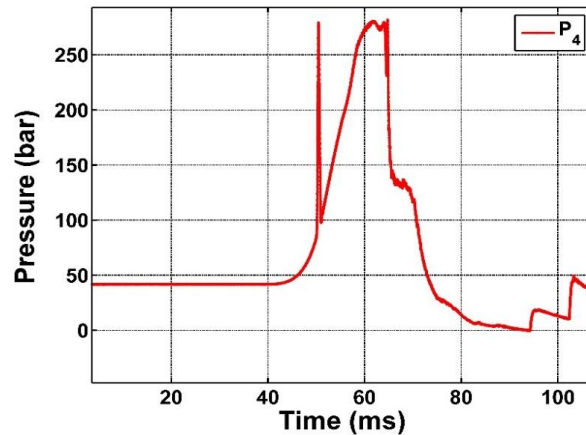


Fig. 2. A typical pressure history in combustion driver

ISRO's HSP crew module underwent extensive testing in shock tunnel. The stagnation and base heat flux were measured in shock tunnel and the measured base heat flux levels match well with the flight data. Also, it was found that due to truncated sphere configuration of HSP, the stagnation point heat flux was found to be 40% high as compared to sphere of similar nose radius and was primarily due to lower shock standoff distance of HSP crew module. A typical shadowgraph showing shock standoff distance on sphere and the HSP of same nose radius is shown in Fig 4.

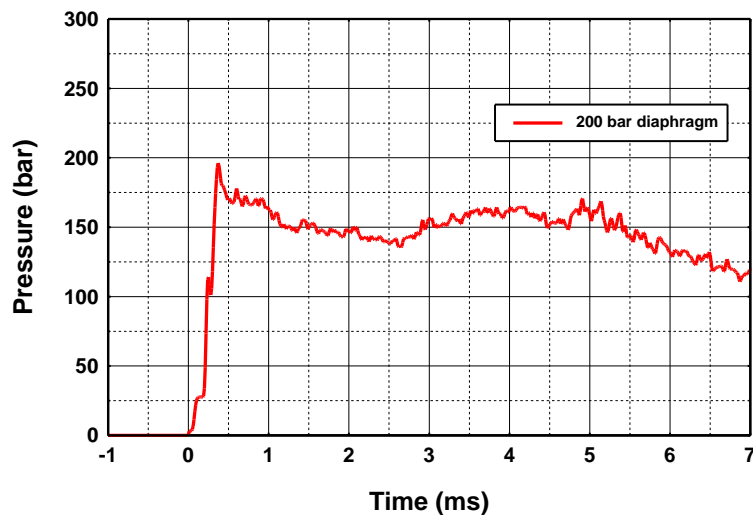


Fig. 3. Pressure history in P_5 for 2.5 MJ/kg

Supersonic combustion on a practical configuration has been successfully demonstrated in shock tunnel at VSSC. Tests were carried out with Air and N_2 as the test gas with gH_2 as the fuel and combustion was clearly demonstrated. In Fig. 5, the pressure rise due to combustion and absence of pressure for N_2 as the test gas can be

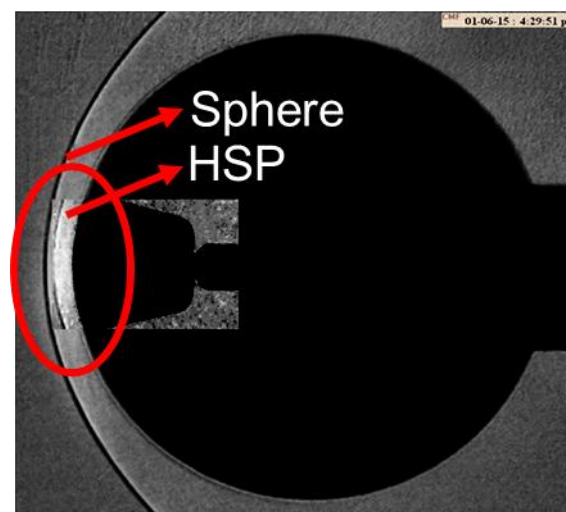


Fig. 4. Shadowgraph showing Shock standoff distance

clearly seen. The key aspects in planning and executing successful air breathing engine testing will be brought out.

With successful demonstration of supersonic combustion, measurement of net thrust on engines with H_2 and Hydrocarbon fuels is being attempted. Also, the tunnel operating envelope is being enhanced up to 12 MJ/kg to meet ISRO's re-entry requirements. Activities relating to this will be highlighted and VSSC's plans for near future will be presented.

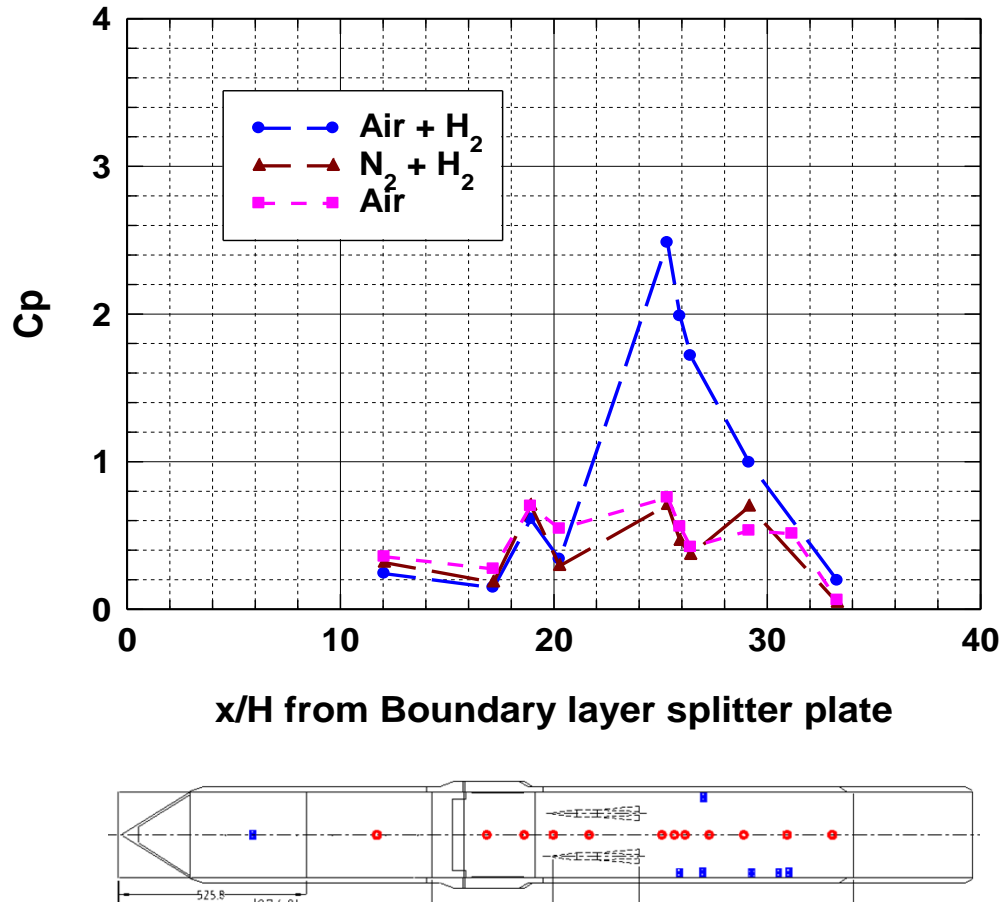


Fig. 5. Pressure rise due to supersonic combustion

4. DESIGN OF INTAKE FOR HYPERSONIC AIR-BREATHING VEHICLE: LESSON LEARNT

*Dr. V. Thiagarajan
Scientist 'G', Deputy Project Director AKASH-NG, DRDL,
Hyderabad-500058*

Introduction

In this lecture, I would like to share our experience in handling the high speed shock dominated flow and how the shocks can be utilized effectively in certain area especially in the design of compression system for hypersonic air-breathing engine. Glass II [1] in his book has defined “shock waves nothing but pressure waves which propagate with a speed exceeding speed of sound of a medium and are created when energy is suddenly deposited in a medium”. Shock waves appear universally in systems which are mathematically expressed by non-linear hyperbolic partial differential equations. Hence, shock waves can exist everywhere in nature when intense energies are released suddenly. Example electrical discharges, explosion, hyper velocities impact etc. or when strong disturbances created in media by supersonic flights. Usefulness shock waves are plenty. In medical field, shock waves are used to discharge kidney stones, orthopedics and also for cancer treatments.

Literature

Historically, X-15 [2] was designed based on the available theory and empirical data (mostly from previous research airplanes). Major gaps in aerodynamic knowledge in understanding the mechanics of airflow for speeds above Mach 3 has been bridged by this shock wave analysis. Valuable part of the X-15 program was to verify the picture of hypersonic flow derived from these shockwave analyses. Another key area where shockwaves are successfully used is the flow control in high speed [3]. Mixing process between fuel and supersonic cross flow before ignition to enhance combustion efficiency, drag reduction missile flight vehicle design to improve the overall performance of the vehicle [4], plasma actuators to minimize separation over aerofoil sections at subsonic speeds, wave drag reduction using pulsed energy deposition (LASER energy deposition) are other areas where shockwaves are effectively used.

Design of compression system for hypersonic air-breathing scramjet engine

DRDL is pursuing the development of “Hyper Sonic Technology Demonstration Vehicle” to demonstrate the hypersonic air-breathing scramjet technology using hydrocarbon fuel. As a part of developmental program, the compression system design, development has been carried out. The essence of the program is:

Design

Flow path of intake has been evolved using oblique shock method considering the exit condition requirements and the geometric restriction so as to meet the scramjet combustor entry conditions.

- Performance parameters such as mass flow rate at the intake entry and static pressure, Mach number and total pressure at the intake exit have been computed at design and off-design conditions [5,6].

Isolated intake tests

- Scaled model of isolated intake have been tested in the Mach numbers 3, 3.5 and 4 at NAL, Bangalore to evaluate the starting characteristics of the intake.
- Based on the test results, the cowl lengths that are to be tested on intake with forebody at hypersonic Mach number have been chosen.

Full configuration test at hypersonic Mach numbers

- A 1:6 scale model of intake with the forebody have been designed with the provision to vary the intake entry area during tests.
- Tests were conducted at the freestream Mach numbers 6 and 7 in the hypersonic wind tunnel facility at Russia.
- Intake starting characteristics of the intake have been evaluated for different operating angles of attack and sideslip conditions. Unstart and re-start angles were obtained at these conditions.
- Intake performance characteristics with the simulation of combustion-induced backpressure (throttling) and pressure recovery with respect to mass flow capture have been evaluated. The maximum allowable back pressure for this intake was evaluated [7,8].
- Hypersonic air-breathing scramjet technology using hydrocarbon fuel is in the verge of demonstration.

Conclusion

Shockwaves are used in many field including medicines. One has to understand the physics of shockwave to utilize effectively.

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5. Blast Waves and Mitigation of Blast Damage

K. Ramamurthi

*Formerly Mechanical Engineering Department,
Indian Institute of Technology, Madras, Chennai*

Blast waves, formed from spontaneous release of energy in an explosion, are decaying shock waves. The blast wave starts off as a strong shock at the source of the explosion and in the far field becomes an acoustic wave. The decaying characteristic is due to the decreasing energy density of the field enclosed by the blast wave front as it progresses. Unlike the case of a shock wave, formed in a shock tube, there is no contact surface pushing it and maintaining its strength. The flow field behind the blast wave front is therefore no longer homentropic as in a constant velocity shock with the result that closed form solutions for the propagation are difficult.

Simple analytical expressions are derived from the global energy conservation equations to illustrate the decay of the blast wave. The overpressure at the shock front can be calculated once the Mach number of the blast wave is known. The variation in the pressure in the flow field due to the decay of the blast wave front causes pressure changes and hence blast wind. There is a change of momentum or impulse associated with the flow field of the blast wave.

The overpressure and impulse are the two major characteristics of the blast wave with the overpressure crushing the object and the impulse disrupting the crushed object from its place. The case of a free field of a blast wave in which the blast does not interact with the ground is first considered for the overpressure and impulse and is followed up when the blast wave interacts with the ground in an actual explosion. The interaction causes reflected shocks, which lead to a roll up with a typical mushroom shape of an explosion.

The idealized geometry of the blast wave could be planar, cylindrical or spherical and the decay of the blast and the flow field depend on it. The interaction of the blast wave with rigid surfaces is highly non-linear in that the compressible non-linearity of the shock causes the reflected pressures to vary depending on the strength of the blast. For strong blasts it could be as high as eight while for weak blasts it is about two if the air is considered to be an ideal gas. The real gas effects at the high pressures and temperatures bring about vibrational excitation, molecular dissociation and ionization and even electronic excitation of the hot gases. These lead to higher values of internal energies with the result that the reflected pressures in a real gas would be very much higher than in an ideal gas. With the internal energy being locked in different forms, the blast wave decays more slowly and hence causes more damage due to air being a real gas at the high temperatures and pressures behind the shock front.

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The near-field region wherein the blast wave is strong is readily modeled through a ‘snow plow’ approximation. Most of the mass swept by the blast is accumulated in a small region near the blast front and it is this mass traveling at high speed that causes the damage.

The transmitted and reflected shocks could be examined in the context of impedance mismatch at the interfaces of the interaction between the object and the blast wave. The conditions for generation of rarefaction and spall of materials are discussed. Considering the non-linearity of the blast wave, prediction of mitigation of blast wave by use of different configurations and matrix of materials is seen to be not very straightforward.

The interaction of blast wave with structures viz., the fluid structure interactions are shown to depend on time scale of the blast overpressure and the characteristic time scale of the structure. For heavy structures the strong blast aggravates the impulse transmitted to it while the opposite is true for light structures. The use of foams and rigid blockages for blast mitigation is discussed.

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6. Blast, Damage and Mitigation Methodologies

Inderpal Singh Sandhu

Scientist

*Terminal Ballistics Research Laboratory, DRDO, Ministry of Defence,
Chandigarh, India-160030*

Detonation of high explosive generate a blast wave in the adjoining media which can create destructive effects on the surrounding environment due to its sharp rise in the peak over pressure. A spontaneous rapid strain resulting from the blast wave loading can produce blast-induced traumatic brain injuries and other injuries which may be fatal. The interaction of blast waves with structures can also cause catastrophic damage to most of the structures. Therefore, the loading and damage arising from the detonation of explosives is an important topic of research these days due to increasing conflicts and terrorist activities.

Different techniques have been proposed in literature as protecting means against the destructive effect of explosion generated by blast waves. New techniques and materials are being used worldwide in designing the protective systems to improve the soldier safety and at the same time boost their operational performance. The best protection approach is to avoid explosion or at least increase standoff from the point of explosion. But other techniques are also required for protection against the deadly effects of explosion. These techniques may include use of mitigation devices designed to absorb, disrupt and ultimately reduce the effect of the blast wave before it reaches the intended target. The protective systems based on these techniques are broadly classified as either active or passive systems. The active systems are based on momentum cancellation and generally use accelerated buffer plates to reduce the effect of incoming blast wave. They require a trigger at appropriate time to act and are generally found to be impractical to deploy in time to prevent damage in the event of an explosion. Moreover, they themselves trigger an explosion to accelerate the plate. On the other hand, passive protective systems do not require a trigger mechanism to deploy and potential passive systems can be broadly classified into four types depending upon their principle of operation. These are impedance mismatching, blast wave disrupters, geometrical arrangements and protective (sacrificial) cladding.

In impedance mismatching technique, a material layer is placed over the main structure such that there is high impedance mismatched. It is based primarily on reflecting the incoming pressure wave and thus reducing pressure loading on main structure. The blast wave disrupter technique involved placement of solid barriers, granular filters or perforated plates between the point of explosion and main structure to disrupt the path of incoming blast wave. In geometrical arrangements, the main intention is to redirect the incoming blast wave away from the target requiring protection. This

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approach is mainly found effective in protection from close in explosion such as landmine blast against armoured personnel carriers. Many materials like polyurethane foams, rubber foam, saw dust, metallic foams etc. have also been reported in literature to use as protective (sacrificial) cladding. The main aim of protective cladding is to reduce the peak pressure loading on the target. It should also be noted that the position of a material in protective system play very important role as incorrect position of material can enhance loading.

The ever-changing face of modern warfare and terrorist activities drives the need for design and development of improved weapon systems & better protective systems. The development of any protective system starts with the design concept evaluation using the analytical equations and numerical simulations in which the appropriate material models are used, selection of materials, fabrication of prototype, scale down testing and then full scale testing of the protective system for its performance evaluation is done.

TBRL is providing support to designer and developer in evaluating their product during design and development stages and also by providing valuable data as inputs for further enhancement of its efficiency. TBRL also help armed and paramilitary forces in selection of appropriate protective systems by evaluating their protective efficiency in instrumented tests and measuring different critical parameters. Many test setups and methodologies have been designed and established for blast evaluation of different protective systems. TBRL has the advantage of very large test ranges for conducting scale down as well as full scale field experiments with high energy materials. In addition to this, the required instrumentation facilities for conducting blast tests are available to evaluate and validate the performance of different protective systems. This include different sensors having very fast response time along with the associated high speed data acquisition systems to record the transient event. Normal and high speed photography is also available to capture the dynamic response of protective system during blast wave loading. New test setups and methodologies are also being developed to evaluate different protective systems as per international standards.

Recently, a shock tube facility was also established and operationalized for conducting basic research in the field of blast wave formation, blast structure interaction and blast mitigation in different materials.

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7. Manipulation of shock tube for generating blast wave for attenuation studies

T. Murugan* & Naveen Raj⁺

*Scientist, Energy Research and Technology Group, CSIR-CMERI Durgapur-713209

⁺Summer intern, MIT Karnataka-576104

The blast wave is a special type of shock wave where the pressure decays immediately after a peak value of pressure is reached (Fig. 1) rather than a constant pressure upstream of the shock. An ideal blast wave is described using a mathematical description of the Friedlander profile [8] which is shown in Fig. 1. Here, P^* shows the maximum or peak overpressure (PoP) of the blast wave and t_d shows the time at which the pressure profile goes below the ambient pressure. The delay constant is represented by b . conventionally, the peak over pressure and the positive impulse calculated using pressure decay and the positive phase duration are used for characterizing the blast wave.

The blast wave related research activities are increasing day-by-day mainly due to the current interest on the understanding of the blast-induced traumatic brain injury [2, 3] and the development of blast wave attenuation techniques [4,5] and blast mitigating structures [6].

The recent increased use of improvised explosives in military conflicts besides the terrorist activities demand for the development of better materials and structures for blast wave attenuation and mitigation. Various experiments had been carried out by researchers all over the world such as Kinney and Grahm [7], Kingery and Bulmash [8], and Sadoyskiy [9] to formulate empirical relations of the blast parameters. However, when a spherical or hemispherical blast occurs, most of the explosive energy is wasted since the parameters can be studied radially outward in any direction, which increases the experimental cost and causes environmental hazards. Also, the physical environmental conditions (local wind, dust, moisture, and temperature) affect the parameters since the explosion is usually studied in an open field rather than a controlled environment.

Nowadays, shock tubes are being increasingly used for generating blast waves in research laboratories to study the blast parameters in a more economical and less hazardous way. They produce the blast wave pressure profile with required peak over pressure at a specific location of interest both inside and outside the tube if the driver section length and pressure are chosen properly [10].

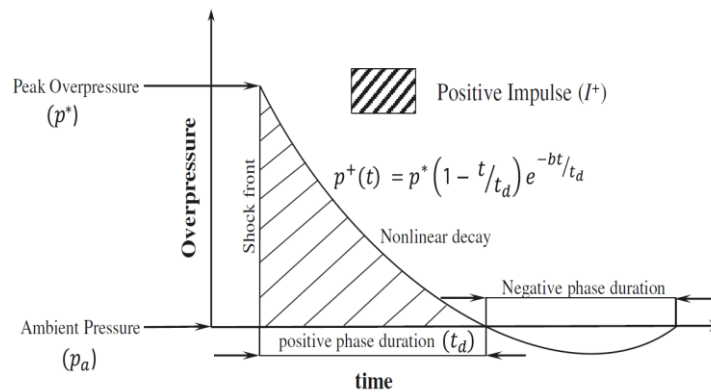


Fig. 1. Schematic of the Friedlander profile [11]

The shock tube is highly efficient as the blast wave propagating inside the shock tube has a linear expansion compared to a spherical expansion of the same produced in the free-field explosion. The lengths of driver and driven section are the crucial parameters for generating a particular nature of pressure history inside the generator such as the Friedlander profile for a given driver section gas and its pressure [11].

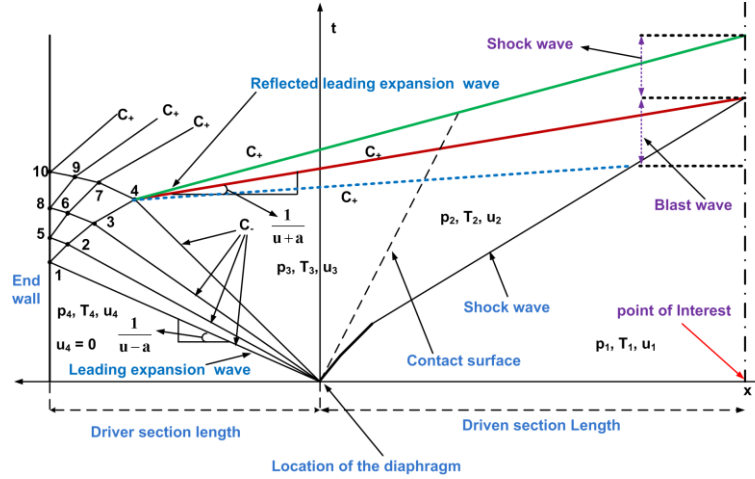


Fig. 2 x-t diagram of a convectional shock tube

Either blast or shock wave is formed at the point of interest (Fig. 2) based on the driver and driven section lengths and gases, pressure ratio across the diaphragm, and the ambient conditions. The pressure remains constant behind the shock wave till the expansion wave reaches the point of interest. However, a continuous reduction of pressure followed by a peak overpressure ensures the formation of blast wave inside the shock tube. The pressure histories obtained at three points inside the shock tube is shown in Fig. 3. A constant pressure followed by the peak pressure at points a & b shows existence of shock wave at these locations. However, a continuous reduction in pressure at point c followed by a peak overpressure ensures the formation of blast wave inside the shock tube.

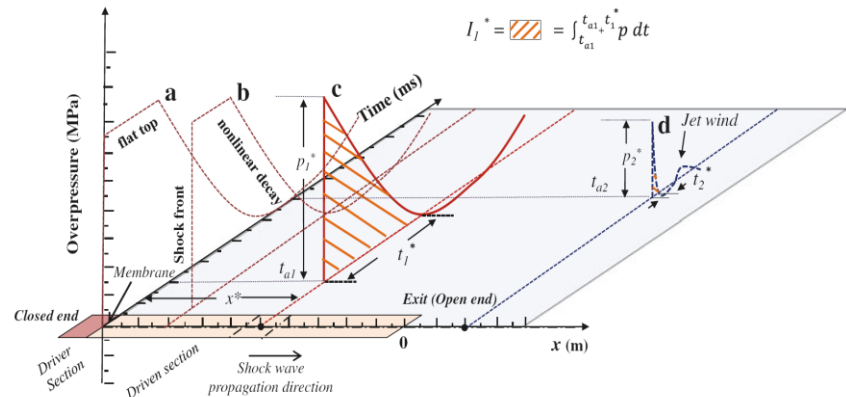


Fig. 3 Evolution of Blast wave inside the shock tube [1]

All the blast parameters for free

field explosion vary with respect to standoff distance d from the blast and explosive weight W of the blast. These two independent variables d and W are united into a single independent variable called scaled distance Z using Hopkinson's cube root scaling law: $Z = \frac{d}{W^{1/3}}$. According to this scaling law, the blast parameters are same for the same scaled distances irrespective of the variation in standoff distances or explosive weights. This enables better characterization of the blast parameters as a function of scaled distance alone. Though a decaying pressure profile similar to blast wave is obtained in shock tube, it is important to find the blast wave parameters for this wave to examine its similarity with the blast wave generated in the free field. Two different shock tube

models are used for numerical simulations to analyze the blast parameters variation for both shorter and longer driven sections of 1m and 6.005m respectively.

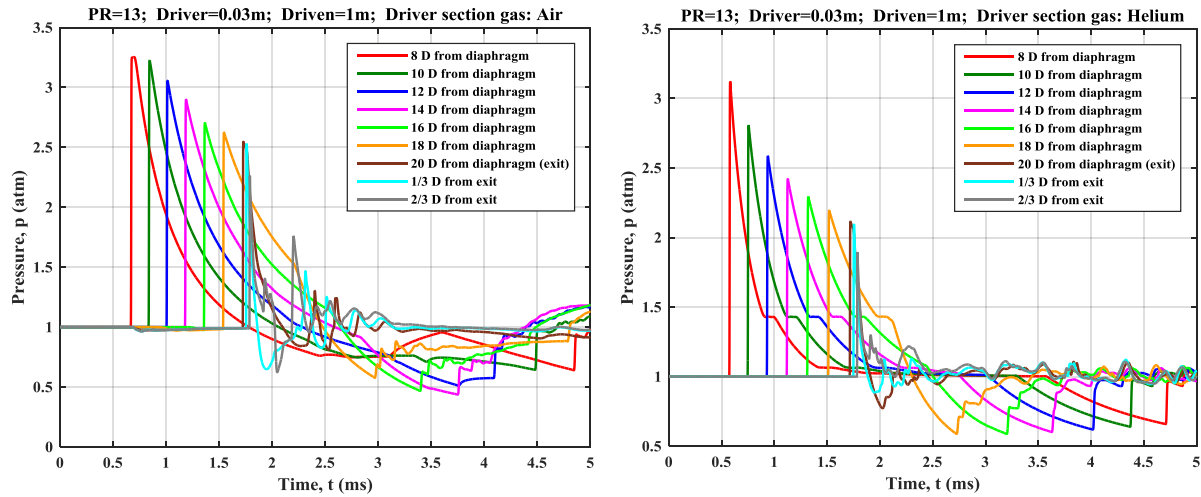


Fig. 4 Pressure histories inside the shock tube with air and helium

The driver section length is chosen appropriately for the pressure ratio of 13 so that the expansion waves and shock front interaction happens within the driven section itself to produce blast waves as shown in Fig. 1. Since our interest lies only in the blast profile, the probes are set from the point where the blast wave starts to occur to get the pressure histories at those points. Further, simulations are also performed by varying the driver section gas (helium) as variation in gas properties will be equivalent to explosive weight variation of a free blast.

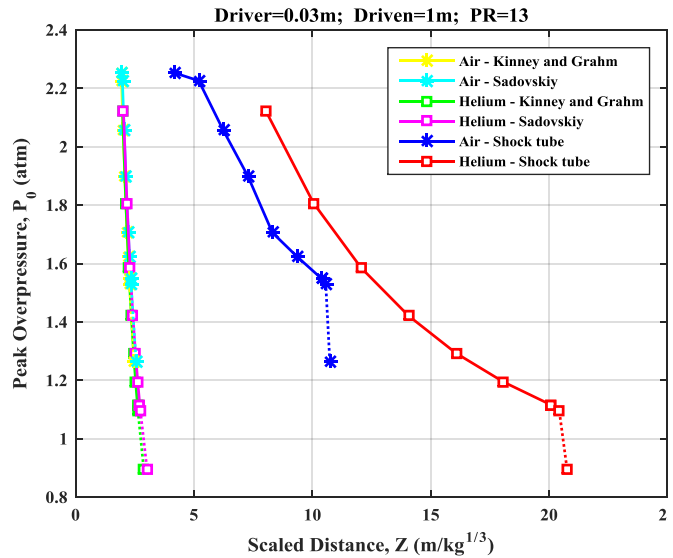


Fig. 5. Variation of peak overpressure with scaled distance

For the numerically simulated blast waves, the peak overpressure values are noted at different locations of the driver section from the pressure histories. Using empirical relations, the respective scaled distances are calculated for those peak overpressures. The locations of these points from the diaphragm are considered as standoff distances in a free air blast. Since both standoff and scaled distances are known, using Hopkinson's cube root scaling law, the equivalent TNT explosive weights are calculated at each location to achieve the same peak overpressure values in a free air blast as in a shock tube. With known scaled distance, standoff distance, and explosive weight, the blast parameters are calculated using empirical relations at each location. The same blast parameters are also calculated for the shock tube generated blast waves with known pressure histories at those locations.

The pressure history obtained inside the shock tube for pressure ratio 13 with air and helium is shown Fig.4. It is clearly seen that the decay profiles are dissimilar in air and helium. Figure 5 shows the variation of peak over pressure with scaled distance for air and helium for pressure ratio 13. Here, the free air blast decay with much faster rate than the shock tube generated blast wave. The variation of peak over pressure with scaled distance for air and helium for pressure ratio 57 is shown in Fig.6. The variation of other parameters such as positive phase duration, impulse per unit area, decay coefficient will be discussed in the talk.

Acknowledgement

The authors gratefully acknowledge the Armament Research Board (ARMREB) of Defence Research and Development Organization (DRDO), India for their financial support.

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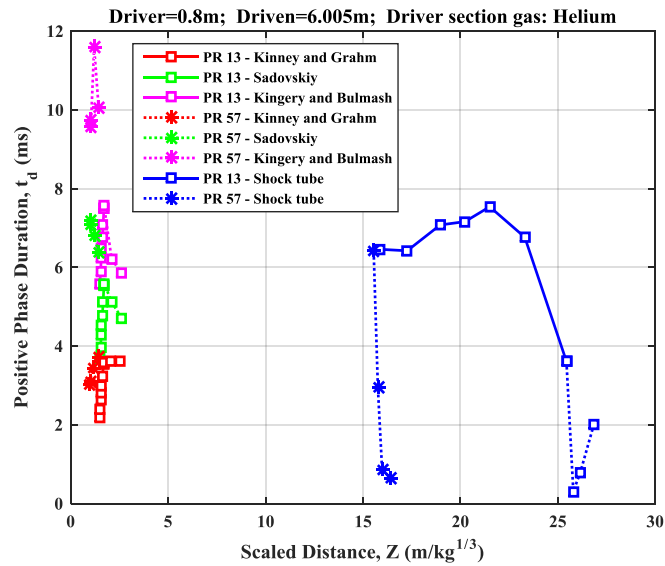


Fig. 6. Variation of peak overpressure with scaled distance for PR=57

8. Thermal shock waves in beam interceptive devices at Facility of Anti-proton and Ion Research (FAIR)

Amit Kumar¹, Abhijit Mahapatra¹, Helmut Weick², Avik Chatterjee¹

¹Advanced Design and Analysis Group, CSIR-CMERI, M.G. Avenue, Durgapur - 713209

²GSI Helmholtzzentrum für Schwerionenforschung GmbH, Darmstadt, Germany

The high energy particle beams in accelerators are required to impinge on specialized targets (mostly solid) and sometimes to halting components called beam stoppers. Mostly, the beam is deposited in form of pulses of high energy and small duration, because of which the thermal shock is a very common cause of failure of such components. The design of targets and beam catchers has been one of the major issues at such facilities and a slew of designs have been developed and tested to that end at UK neutrino factory [1], CERN [2], J-PARC/MUSE [3], T2K [4].

Facility for Antiproton and Ion Research (FAIR), an international accelerator and experiment facility, is being built at GSI Helmholtzzentrum für Schwerionenforschung, Darmstadt, Germany (Figure 1). FAIR was founded on 4th October 2010 and will be fully operational by 2025. India is a founder member and the third largest shareholder in FAIR science project and is represented by Bose Institute - Indo Fair Coordination Centre (BI-IFCC), formed by Department of Science and Technology (DST) and department of Atomic Energy (DAE). India's participation is in the area of design and development of magnets, detectors and beam catchers (<http://bic.boseinst.ernet.in/bi-indo-fair-coordination-centre>). An MOU was signed between CSIR-CMERI and BI-IFCC on 22nd July 2014 for design of beam stoppers as one the critical in-kind contribution from India.

At FAIR [5], a wide range of ions with energies up to 1.5 GeV/ nucleon (92% of speed of light) will be used for the production of fragments by projectile fragmentation/fission at the superconducting fragment separator (Super-FRS). Rare isotopes of all elements up to uranium will be produced and spatially separated within a few hundred nanoseconds, enabling the study of very short-lived nuclei. The schematic of Super-FRS at FAIR is shown in Figure 2, depicting the position of target and beam catchers (BC). The specification of a beam catcher for fast extraction is with 0.4-1.5 GeV/nucleon primary beam of ^{238}U in the order $\sim 5 \times 10^{11}$ pps (particles per spill), depositing 29 kJ energy in the absorbing medium (graphite) within a pulse of 50-100 ns duration, interval between two consecutive pulses being 1.67s. The energy (particle flux)

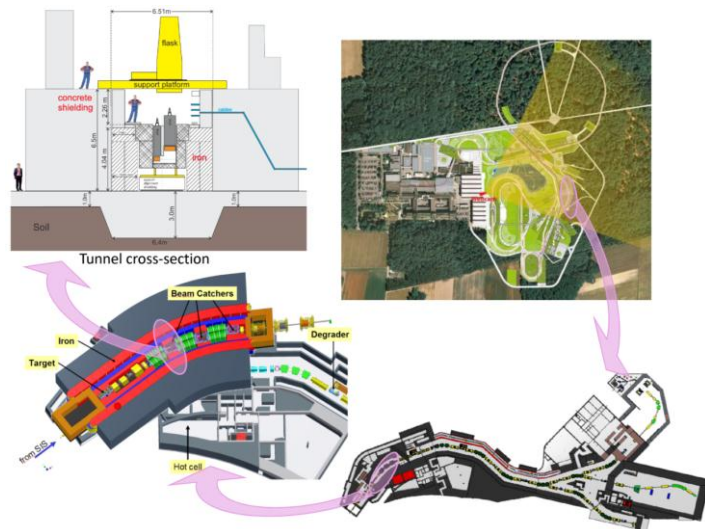


Figure 1: Facility Layout at GSI Darmstadt

distribution across the beam cross-section is estimated to be two dimensional Gaussian, NATIONAL WORKSHOP ON SHOCK AND BLAST WAVE RESEARCH IN INDIA: THE PAST, PRESENT, AND FUTURE (NWSBRI-2017) OCTOBER 12-13, 2017

and the energy deposition along the path direction is calculated by the stopping power for fast heavy ions in matter. The localized high energy deposition density towards the end of the heavy ion's range in the catcher (so called Bragg peak) causes the peak energy density in BC to be as high as 300 J/g per pulse and the instantaneous power during the pulse to be as high as 570 GW. The high amount of deposition is expected to induce thermal shock waves in the beam catchers and is one of the major challenges in design of beam catchers for this facility.

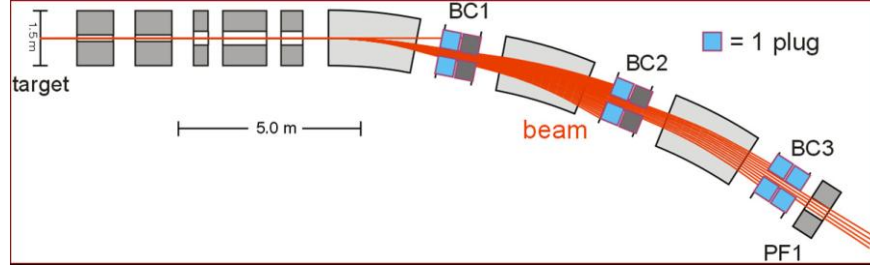


Figure 2: Schematic of location of beam catchers in the magnetic separator beam line

A coupled thermo-mechanical analysis is needed to predict the transient stresses due to the thermal shock. Biot [6] was the first to introduce the two-way thermomechanical coupling by including a strain rate term in the thermal equilibrium equation, in departure from the conventional uncoupled thermo-elasticity. The transient coupled thermo-mechanical analysis of the pulsed form deposition of the beam is carried out using non-linear finite element code LS-DYNA® to study the generation and propagation of pressure waves within the absorber medium. The complete energy of 29 kJ is deposited in the form of pulse of duration 50 nanoseconds. A sequence of such pulses is deposited where the interval between consecutive pulses is 1.67 s. The geometry of the absorber and segmentation of heat deposition zone is shown in Figure 3.

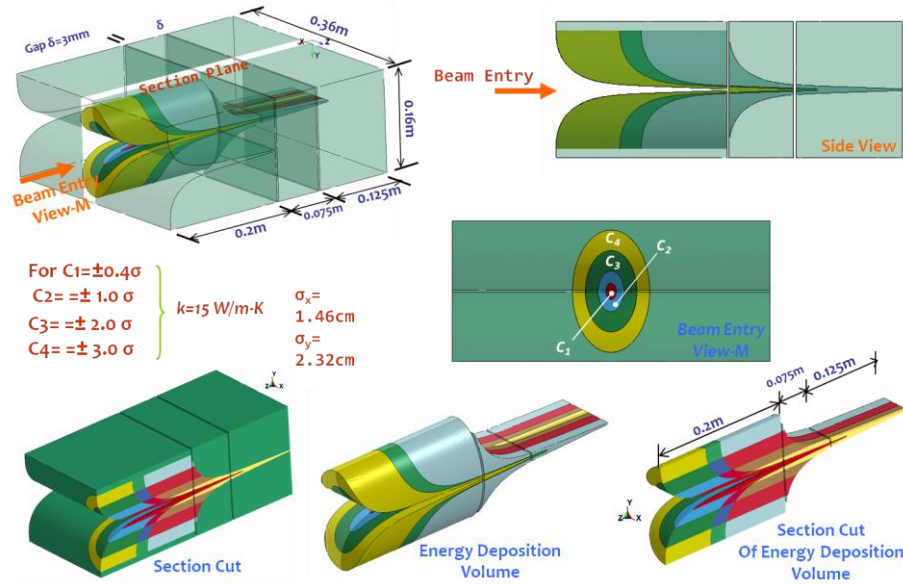


Figure 3: Geometry of absorber and heat deposition zone segmentation

The transient analysis is performed using explicit time integration and small time steps till the 100 μ s of pulse deposition, which is then switched to implicit time

integration and large time steps and is in implicit mode till the next beam pulse i.e. 1.67 seconds. Temperature dependent thermo-mechanical properties of Graphite (SGL R6650) as given in [7] are used in the computations. To account for the degradation of thermal conductivity due to irradiation damage of the Graphite, small conductivity of 15 W/m-K is considered in deposition zone. The obtained values of instantaneous temperature rise and pressure rise are compared with respective theoretical values in Table 1. A significant agreement is obtained between the theoretical and computational results.

Table 1: Comparison of theoretical and simulation results

	Max. Temp rise (K) (Simulation)	Max. Temp rise (K) (Theoretical)	Pressure rise (MPa) (simulation)	Pressure rise (MPa) (Theoretical)
1st pulse	134.3	133	10.72	10.70
2nd pulse	124	123.5	9.34	9.36
3rd pulse	119	119.3	8.74	8.77

Theoretical Temperature rise $\Delta T = U/c_p$. $U = 102.3$ J/g, c_p (Specific heat capacity) is taken as average in the temperature range. Theoretical pressure rise $\Delta p = \alpha E \Delta T / (1 - 2\nu)$. The wave propagation phenomena is visualized in Figure 4 where iso-surface pressure contour in the absorber at different instances are shown.

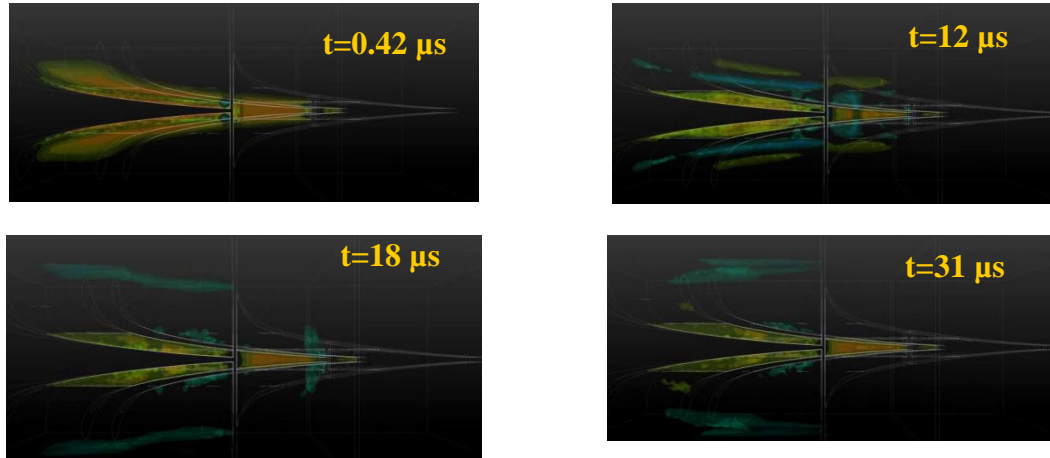


Figure 4: Iso-surface contours inside absorber volume at different instances

Further, the propagation of pressure wave along height is quantitatively shown in Figure 6 by plotting pressure variation at mid-section locations A - E along height (marked in Figure 5) with time. Locations A, B, C, D coincide with 0.4, 1, 2 and 3 times standard deviation along height (y), while location E lies on the outer surface of the absorber. The negative pressure (tensile stress) pulse can be observed

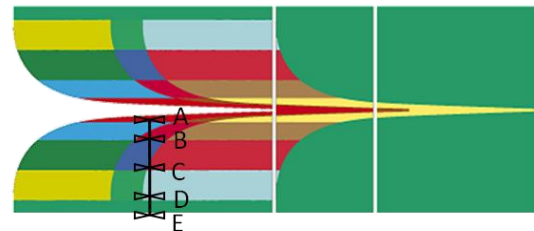


Figure 5: Locations A-E along absorber height

passing through different locations at different instances. For location C (blue curve), the peaks 1, 2 and 3 are original wave, wave reflected at outer surface boundary (fixed) and wave reflected at curved boundary (free) respectively. The magnitude of the pulse doubles at the boundary (magenta line) due to the constrained displacement boundary condition. The failure of brittle material like graphite is usually in the form of cracking and spalling and is determined by the maximum and minimum principal stresses present and the ultimate tensile (σ_{ut}) and compression stress (σ_{uc}) limits. The Coulomb-Mohr failure criteria is used to compute the factor of safety of the stress states.

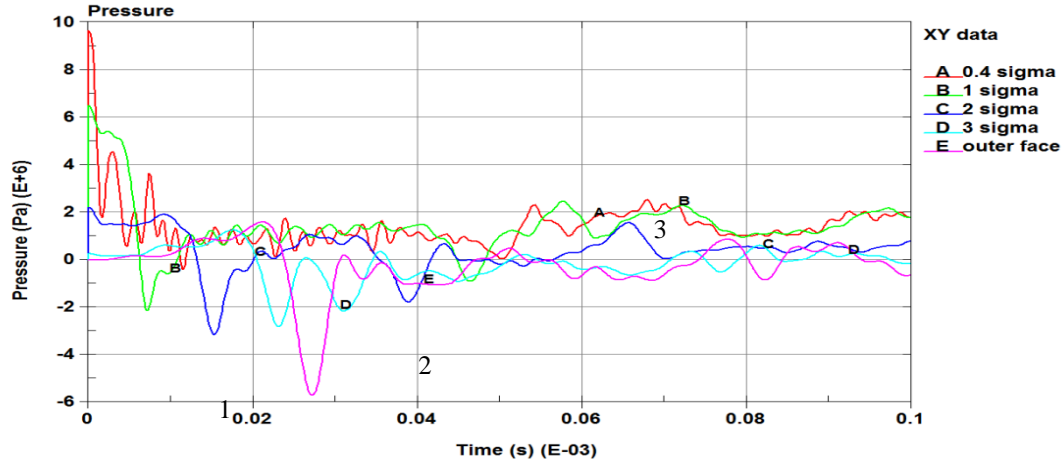


Figure 6: Pressure variation with time at different locations along height

Acknowledgement

This work is currently ongoing at CSIR-CMERI, Durgapur under DST-DAE grant through BI-IFCC, Govt. of India. The beam properties and interaction data is provided by GSI Darmstadt.

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9. Overview of Research and Development activities at CSIR-CMERI

Dr. Nagahamaiah

Head, Planning and Performance Division, CSIR-CMERI, Durgapur

Email: naga@cmeri.res.in; pme@cmeri.res.in

This presentation aims to give an overview of CSIR-CMERI research focus, achievements and the benefits accrued to society.

Technology overview

CSIR-CMERI is the only National level research institute in the field of mechanical engineering in India and is mandated to conduct cutting edge research in the broad area of mechanical engineering along with allied engineering disciplines. Mechanical engineering technology accounts for a significant portion of the import in terms of process know-how, engineering hardware and equipment. It is also mandated to foster indigenous development of mechanical engineering technology for the industry in attaining self-reliance.

CSIR-CMERI has developed several technologies during April 2012 to March 2016 which have direct or indirect technological relevance and impact. The Institute has substantially contributed through R&D efforts to the front-line areas of research such as Robotics; Mechatronics; Microsystems; Manufacturing; Thermal Engineering; Tribology; Farm Mechanization; Cybernetics, Electronics, Control & Embedded Systems; Near Net Shape Manufacturing and Biomimetics. Though impact assessment of the developed technologies are not carried out through the engagement of External Agencies, it is apparent that these technologies potentially impact indigenization/import substitution, economic growth, energy security and environment protection, strategic applications, skill development and many others.

CSIR-CMERI has a major footprint in the development of the robotic and mechatronic systems and technologies. CSIR-CMERI has developed some very useful technologies in the domain of robotics which comprise the Autonomous Underwater Vehicle (AUV), Remotely Operated Vehicle (ROV), Sub-terranean robot, All-terrain Robot and mobile robotic system for visual inspection, etc., all of which have really helped towards development of expertise and skilled manpower in the area of deep water robotic technologies for the successive development based on demand and requirement and preparedness to develop autonomous mobile robotic systems for civilian and strategic applications. As such the Parliamentary Standing Committee has acknowledged the capability of CSIR-CMERI in Robotics.

CSIR-CMERI also provide the need of power and mining industries by assessing remaining life of allied machineries, Condition Monitoring of different industrial machineries and structures to avert sudden breakdown or any loss to human life and properties and also prevent from huge loss of Industries in revenue generation. The calibration testing facilities in mass, volume, pressure and temperature cater the need of various private, government or public sector industries in eastern part of the country to maintain the quality of their products. Besides R & D support, the institute also renders technical support to different Indian Industries such as Automobile, Aerospace, Power, Steel, Mining, Energy etc.

Benefits accrued to Society

Technology impacts the environment, people and the society (i.e. country at large) as a whole. Technology Impact Study or Technology Assessment Study is a scientific, interactive and communicative process that contributes to the evaluation of the public opinion towards societal and economic aspects of science and technology. Besides conducting cutting-edge research, CSIR-CMERI is also dedicated towards different R&D based mission mode programs of the country to provide suitable technological solutions for poverty alleviation, societal improvement, energy security, food security, and pure water.

Though impact assessment of the developed technologies are not carried out through the engagement of External Agencies, it is apparent that these technologies potentially impact indigenization/import substitution, economic growth, energy security and environment protection, skill development and many others. It can be said without prejudice that if one considers only the Swaraj Tractor which was developed by CSIR-CMERI, one can visualize what tremendous impact this technology had on the Indian society in terms of self-reliance, production, employment generation and revenue earning. This is clearly visible through a recent impact study carried out by external agencies on societal and economic paradigm on the two premium technologies i.e., Swaraj and Sonalika tractors developed by CSIR-CMERI, during seventies and nineties respectively. It is found that, the two technologies have direct value economic impact of around Rs. 12000 Crore.

Yet another addition to the stable of tractors developed by CSIR-CMERI was the KrishiShakti Tractor. The KrishiShakti, a small 10-12 hp tractor designed and developed by CSIR-CMERI was an apt response to the necessity of enabling farm mechanization in an affordable manner. Furthermore, this small tractor and its matching implements are based on diesel engines and tractor parts readily available in the market. As a new leaf in CSIR-CMERI's efforts to empower the Indian farmers, the KrishiShakti tractor received CMVR Certification as an Agricultural Wheeled Tractor after rigorous trials and testing. The Technology of KrishiShakti has been transferred to M/s Singha Components Pvt.

Ltd., Howrah, West Bengal, who would soon manufacture KrishiShakti. This would benefit Indian farmers possessing small land holdings. The development has bridged a long felt technology gap.

The “Solar Power Tree” innovatively addresses the challenge of increasing demand for green energy by gainfully utilizing scare land resources in the country. It helps harness maximum solar energy in minimum space. It takes very less land area of only 4 sq ft for a 5 KW solar power tree as compared to 400 sq ft of land area required in case of conventional system. The Solar Power Trees developed are deployed to cater to this requirement in the society.

Improved Iron Removal Plant developed has enormous social impact especially under the rural development mission of the Govt. of India. This type of initiative of CSIR-CMERI is creating an example of societal service provided by the research and development organization in India to the people of India. More & more peoples are benefitted by this durable, chemical free, user friendly IIRP which runs without electricity, creating for a source of income to the manufacturers and has wide opening of employment to the younger generation of rural area.

CSIR-CMERI is also engaged in determining available underground water in more than 50 identified plots for the purpose of rehabilitation of approximately 44598 households who are presently residing over the 126 declared unstable zone in Raniganj Coalfield area. Rehabilitation process will save the life of such huge population from any sudden unpredicted subsidence of land and fire.

The Government of India has recently placed a major emphasis on making available technological solutions to the people of North East India, through the provision of research outputs for typical issues related to the area, and also on their implementation so that the region can emerge as a strong economic entity. CSIR-CMERI, Durgapur has a strong presence in the northeast state of Mizoram where the Institute is for providing appropriate technological solutions for employment generation and its sustainability. The **CSIR Centre for Post-Harvest Processing & Research** established in Tuirial, Mizoram is striving to establish a model of how science and technology can transform the lives of the common people.

Major Recent Technologies of CSIR-CMERI

- ✚ 10-12 HP Small Tractor ‘KrishiShakti’
- ✚ Cabinet dryer for ginger and turmeric
- ✚ Fluidized Bed Dryer for Agro Crops
- ✚ Generation of Syngas through Plasma Gasification of Plastic Waste
- ✚ Remotely Operated Vehicle (ROV)
- ✚ Coconut De-husking Machine
- ✚ Reconfigurable Micro-factory
- ✚ Metal Injection Molding
- ✚ High Speed Spindle for Micro Milling & Drilling Operations
- ✚ Five Axis CNC Micro-Milling Machine
- ✚ Autonomous Intelligent Robotic Wheel Chair - Low end low cost model
- ✚ Medical Device-COLPOSCOPE
- ✚ Semi Continuous Bio-Diesel Plant
- ✚ Mobile Bridge Inspection Unit MBIU
- ✚ Inter Row Rotary Cultivator for wide-row crops
- ✚ Improved Iron Removal Plant
- ✚ Pluggable Smart Energy Meter
- ✚ Iron Removal Filter
- ✚ Domestic arsenic water filter
- ✚ Domestic filter for defluoridation of water
- ✚ Salivary Fluoride Detection Kit
- ✚ Digital Kiosk
- ✚ Smart Card Operated Prepaid Energy Meter
- ✚ Solar Power Tree